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ANDERS HEYDEN )

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**TRANSMITTAL OF VERIFIED ENGLISH  
TRANSLATION OF PROVISIONAL APPLICATION**

Technology Center 2600

Assistant Commissioner for Patents  
Washington, D.C. 20231

Sir:

This Application claims priority under 36 U.S.C. § 119(e) for the filing of U.S. Provisional Application No. 60/150,440 on August 24, 1999. Such Provisional Application was filed in the Swedish language.

An accurate verified English translation of U.S. Provisional Application No. 60/150,440 prepared by Margareta Backen and dated October 27, 1999 now is provided.

Respectfully submitted,

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Date: March 11, 2002

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## VERIFIED TRANSLATION

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I, the undersigned Margareta Backen, technical translator, of Bellevuevägen 46, S-217 72 MALMÖ, Sweden, do hereby declare:

- (1) That I am well familiar with the Swedish and English languages;
- (2) That the attached is a true and accurate translation into the English language of the Swedish text of this Patent Application entitled "Microscope" that was filed in the US Patent and Trademark Office on 24 August 1999.
- (3) That all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both under § 1001 of title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Date: this 27th day of October 1999

Margareta Backen



UNITED STATES PATENT APPLICATION

OF

ANDERS HEYDEN

FOR

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### Field of the Invention

The present invention relates to a microscope having an image processing system and a method for such a microscope.

### Background of the Invention

Microscopes are frequently provided with a camera for recording digital images. The digital image can then be processed in a number of different ways. For example, biological preparations are studied under a microscope provided with an image processing system. The image processing system can then be used to recognize a certain type of organisms or cells to be able to automatically determine the presence of the organism or cell in the specimen.

However, it is sometimes difficult to obtain a sufficiently sharp image to be able to easily carry out automatic recognition and determination of a special type of organisms. This relates especially to small organisms or cells.

For easier automatic recognition, it is possible to use digital filters to improve the contrast in the image and, thus, make it easier for the image processing system to automatically recognize the cells or organisms.

A standard method of improving the contrast in an image is what is referred to as the High-Boost method, in

which the image is multiplied by a factor, whereupon a low-pass filtered image is subtracted from the result of the multiplication.

US Patent 5,696,850 discloses a method and a system using an algorithm for increasing the sharpness of reproduced images, the system having a digital camera and a reproduction device. According to the method, the transfer functions of the camera and the reproduction device are determined by measuring them accurately. However, the measuring operation requires advanced and expensive apparatus and is carried out in one direction at a time since it is difficult to make a two-dimensional measurement of the transfer function. Besides, the measurement of the optical transfer function must be effected each time something has been changed in the optical system. Then the inverse Fourier transform of the two combined transfer functions is used to calculate a one-dimensional filter. The filter is used to filter a recorded image by first applying the filter in one direction and subsequently in a direction at right angles to the first.

However, satisfactory results are not achieved by the prior art techniques. Nor is it possible to measure the transfer function for a microscope in the same accurate way as for a camera.

A further problem of the method and the device according to the US patent is that the noise at high frequencies will be amplified in an uncontrolled manner if the value of the transfer function is small for high frequencies. Moreover, a satisfactory result is not achieved with two one-dimensional filters applied successively.

There is thus a need for a method and a microscope with an image processing system which increase the sharpness of an image while at the same time the noise is restricted.

#### Summary of the Invention

An object of the present invention is to provide a microscope, which increases the sharpness while at the same time the noise is restricted in an image taken by means of the microscope.

A further object of the present invention is to provide a method for recording and processing of digital images so as to obtain sharp images.

These objects are achieved by a microscope and a method for the same according to the appended claims.

A microscope with an image processing system according to the invention comprises an object holder, optics which in an image plane form an image of an object placed in the image holder, and a digital image sensor, which has a number of sensor elements, for recording the image.

A microscope according to the invention is characterized in that the image sensor and the image plane are arranged in such manner that the spatial frequency of the sensor elements is higher than the maximum spatial frequency of the image. The microscope further comprises at least one calculating means connected to the sensor, a first calculating means being adapted to provide a two-dimensional filter function, which essentially has a first value at the spatial frequency zero, a value greater than zero at a spatial frequency above the maximum spatial frequency of the image and a peak value between the spatial frequency zero and the spatial frequency of the second value, to calculate a digital filter corresponding to a two-dimensional inverse transform of the filter function, and to filter a recorded image by means of the digital filter.

The filter function decreases toward zero for spatial frequencies above the spatial frequency of the peak value.

The first value is preferably one since no attenuation usually occurs at the spatial frequency zero. It is, however, possible to have amplification also at the spatial frequency zero in the image.

The spatial frequency of the sensor elements is defined as the inverse of the double distance between two adjoining sensor elements.

Preferably, the microscope is adapted to calculate a digital filter when a user initiates such calculation. Alternatively, the microscope is adapted to calculate a digital filter each time a new image is recorded by means of the image sensor, which, however, does not yield any particular advantages.

By using a two-dimensional filter, it is possible to obtain a rotationally symmetrical result. By the spatial frequency of the sensor elements being higher than the maximum spatial frequency of the image, it is possible to use a digital filter, which corresponds to a filter function which has a value different from zero at frequencies above the maximum spatial frequency of the image. The use of such a filter results in noise reduction in the image.

According to an alternative embodiment, the filter function is a convolution of two one-dimensional filter functions. The digital filter, however, will then not be rotationally symmetrical.

The image sensor is advantageously a semiconductor sensor in the form of, for instance, a CMOS sensor or a CCD (charge coupled device) which is composed of a number of sensor elements equidistantly spaced from each other.



The spatial frequency of the sensor elements is the inverse of the double distance between two adjoining sensor elements.

However, the image sensor can be some other kind of image sensor such as a vidicon. What is essential for the invention is that the image sensor has a better resolution than the maximum spatial frequency of the image.

Preferably, the sensor elements have a spatial frequency which is at least 1.5 times, advantageously at least 2 times higher, than the maximum spatial frequency of the image.

According to a preferred embodiment of the present invention, the microscope also comprises an input means for inputting values providing information about the filter function.

Preferably, the microscope is adapted to make an estimate of the limit frequency of the optics by recording an image by means of the image sensor. The recorded image is Fourier-transformed so that an image in the frequency plane is obtained. The first calculating means calculates on the basis of the Fourier-transformed image a limit frequency. The integrated signal up to the limit frequency is the major part of the total light energy of the image and advantageously at least 90%, preferably at least 95%, of the total light energy in the transformed

image. The limit frequency measured in the manner described is not the same as the maximum frequency which the optical system lets through, but is a usable estimate thereof.

The limit frequency is used to calculate the position of the peak value of the filter function. It is advantageous to let the position of the peak value depend also on the values of the appearance of the filter function, which are inputted with the aid of the input means.

If the microscope is adapted to estimate the limit frequency, the estimate is preferably made when a user initiates such an estimate, but alternatively the estimate is made each time a new image is recorded.

The filter function is advantageously strictly increasing up to the limit frequency and subsequently strictly decreasing so that the filter function up to the limit frequency conforms as far as possible with the inverse of an actual transfer function. As a rule, an actual transfer function is strictly decreasing up to the maximum frequency which the optical system lets through.

It is possible within the scope of the invention to have a filter function which is neither strictly increasing up to the limit frequency nor strictly decreasing after the limit frequency.

It is advantageous to let the filter function be continuously derivable since this allows a digital filter having a smaller spatial extent and, thus, a more rapid filtration.

It goes without saying that the above features can be combined in the same embodiment.

In order to further illustrate the invention, detailed embodiments thereof will now be described, without the invention being considered to be restricted thereto.

#### Brief Description of the Drawings

Fig 1 is a schematic view of a microscope according to an embodiment of the present invention.

Fig. 2 is a block diagram of the function of a microscope according to the invention.

Fig 3 illustrates the filter function as a function of the frequency in a microscope according to the present invention.

Fig. 4 shows a digital filter according to the present invention.

#### Detailed Description of the Invention

Fig. 1 is a schematic view of a microscope according to the present invention. The microscope has a source of light 1, which illuminates an object 2 placed on an object holder 3. Light from the object is collected with a microscope objective 4. A digital image sensor is ar-

arranged at a distance from the microscope objective 4. According to this preferred embodiment, the digital image sensor is a CCD. The CCD 5, the microscope objective 4 and the object 2 are arranged in a spaced-apart relationship so that the image plane of the microscope objective coincides with the surface of the image sensor 5. The CCD is formed with a large number of sensor elements 6 which are mutually spaced apart a distance  $d$ . Each picture element corresponds to a pixel in a digital image. The image sensor 5 is connected to an image processing means 7, which in turn is connected to a display 8 and an input means in the form of a keyboard 9. In the image processing means, a first calculating means 24 and a second calculating means 25 are arranged. Between the microscope objective 4 and the CCD 5, lenses 10 are arranged to transfer the image to the CCD 5. The optical system consisting of the microscope objective 4 and the lenses 10 has a combined transfer function which describes how different spatial frequencies of the object 2 are transferred to the image plane. Depending on the design of the objective 4 and the lenses 10, spatial frequencies of different degrees are transferred from the object 2. The maximum spatial frequency that is transferred from the object 2 to the CCD 5 is usually defined as the resolution of the optical system. Thus only structures corre-

sponding to a certain minimum size of the object will be distinguished in the image. The size of the image, however, may vary by varying the mutual arrangement of the CCD 5, the microscope objective 4 and the object 2. The spatial frequency of the sensor elements is defined as the inverse of their double mutual distance  $2d$ . According to the invention, the object 2, the microscope objective 4, the lenses 10 and the CCD 5 are arranged so that the spatial frequency of the sensor elements is higher than the maximum spatial frequency of the image. The spatial frequency of the sensor elements is preferably 1.5 times higher than the maximum spatial frequency of the image and advantageously at least 2 times higher than the maximum spatial frequency of the image in order to obtain a reduction of noise.

When an object 2 is placed on the object holder 3, an image will be recorded by the image sensor 5. The recorded image is transferred to the image processing means 7, which processes the image before it is shown on the display 8. The image processing in the image processing means 7 is affected by parameters which are inputted via the keyboard 9.

Fig. 2 is a block diagram of the function of the image processing means 7. The recorded image from the CCD 5 is inputted at the top of the figure to block 12 and at

the bottom of the figure to block 13. In block 13, a division into the color components of the image is made, whereupon the divided image is transferred to block 14 for filtration by means of a digital filter. In block 12, a limit frequency ( $\omega_0$ ) is determined by the recorded image being transformed, whereupon  $\omega_0$  is calculated as the frequency below which 95% of the integrated signal in the transformed image is present. The calculation of  $\omega_0$  can be carried out each time a new picture is taken or when a user of the microscope initiates a determination of  $\omega_0$ .

According to the preferred embodiment, a digital filter is calculated when a user initiates such a calculation via the keyboard 9.

Fig. 3 shows a filter function as a function of the frequency which describes an amplification as a function of the frequency.

In block 15, parameters for the transfer function of the filter are fetched from the keyboard or from a memory 23 in the image processing means. Examples of the parameters that can be fetched from the keyboard 9 in block 15 are the amplification of the filter at the limit frequency, the position of the limit frequency and the appearance of the filter function above and below the limit

frequency. In block 16, the transfer function 17 of the filter is determined on the basis of the parameters that are fetched into block 15. The filter function 17 is determined as follows:

$$H_f(\omega) = \begin{cases} e^{(\omega/\omega_0)^2 \alpha}, & \omega \leq \omega_0, \\ e^{\alpha \left( \frac{\omega_1^2 + \omega_0^2}{\omega_1^2 + \omega^2} \right) \gamma}, & \omega \geq \omega_0, \end{cases}$$

wherein  $\alpha$ ,  $\gamma$  and  $\omega_1$  are parameters which the user can modify in the input means 9. The parameter  $\omega_0$  can either be defined by the user or be determined automatically by the system and indicates the limit frequency. The amplification at the limit frequency is determined by  $\alpha$ .  $\gamma$  and  $\omega_1$  determine how rapidly the filter fades away at high frequencies.

Thus, the filter function is two-dimensional and dependent on the sum of the frequency  $\omega$  but independent of an angular parameter, a circular symmetrical function being obtained.

The filter function, however, may have a different appearance and can, for instance, be described by one polynomial up to the limit value and another polynomial above the limit value. The filter function 17 has essentially the value 1 for the frequency zero and a peak

value at the limit frequency ( $\omega_0$ ). After the limit frequency  $\omega_0$ , the function decreases. The filter function has, however, a value different from zero above a frequency exceeding the maximum spatial frequency of the image. The limit frequency essentially conforms to the maximum spatial frequency of the image. Once more with reference to Fig. 2, there is made in block 18 a two-dimensional inverse transform of the filter function which was calculated in block 16. The inverse-transformed filter function is digitized and cut off to a suitable size to constitute a digital filter for the recorded image. In block 14, the image of which the colors have been divided is filtered two-dimensionally by means of the digital filter. Subsequently, a voluntary gray-level transformation is made in block 19, whereupon the colors in the image are again put together in block 20. The gray-level transformation is carried out if there is a risk that the gray levels have reached outside permissible values in the filtration. After the processing of the image, the image is shown on the display 8 or stored in a storage means 26.

Fig. 4 illustrates an example of a digital filter 22 which is used in block 14. As is evident from Fig. 4, the filter is circular symmetrical around the top 21. When the image is filtered in block 14, the value in a pixel



is multiplied by a value corresponding to the filter at the top 21 and added to the result of the multiplications between the adjoining pixels and a corresponding value in the filter.

A person skilled in the art realizes that the invention is not limited to the embodiment shown and that many modifications are feasible within the scope of the invention. For example, block 12 in Fig. 2 can be omitted and the filter function be determined entirely by means of parameters that are inputted via the keyboard 9 in Fig. 1. A person skilled in the art also realizes that blocks 13 and 20 can be omitted if the image is not a color image.

What I claim and desire to secure by Letters Patent is:

1. A microscope comprising  
an object holder (3),  
optics which in an image plane form an image of an  
object (2) which is placed in the object holder, and  
a digital image sensor (5), which has a number of  
sensor elements (6) for recording the image, c h a r -  
a c t e r i z e d in that the image sensor and the image  
plane are arranged in such manner that the spatial fre-  
quency of the sensor elements (6) is higher than the  
maximum spatial frequency of the image, the microscope  
further comprising at least a first calculating means  
(24) which is connected to the image sensor (5) and which  
is adapted

to provide a two-dimensional filter function, which  
essentially has a first value at the spatial frequency  
zero, a second value which is different from zero at a  
spatial frequency above the maximum spatial frequency of  
the image and a peak value between the spatial frequency  
zero and the spatial frequency of the second value,

to calculate a digital filter which corresponds to a  
two-dimensional inverse Fourier transform of the filter  
function, and

to filter a recorded image by means of the digital  
filter.

2. A microscope as claimed in claim 1, characterized in that it also comprises an input means (9) connected to the calculating means for inputting values which provide information about at least one of the peak value of the filter function, the spatial frequency of the peak value, the filter function for spatial frequencies below the spatial frequency of the peak value, or the filter function for spatial frequencies above the spatial frequency of the peak value, the inputting means being connected to the calculating means and the inputted values being used by the calculating means to provide the filter function.

3. A microscope as claimed in claim 1 or 2, characterized in that it also comprises a second calculating means (25), which is connected to the image sensor and the first calculating means, and which is adapted

to Fourier transform the recorded image,

to determine a limit frequency below which the major part of the light energy of the transformed image is to be found, and

to provide the first calculating means with the limit frequency as a value of the position of the peak value.

4. A microscope as claimed in claim 3, characterized in that the limit frequency is determined as the frequency below which at least 90% of the energy in the image is to be found.

5. A microscope as claimed in claim 1, 2 or 3, characterized in that the spatial frequency of the sensor elements is at least 1.5 times higher, and preferably at least 2 times higher, than the maximum spatial frequency of the image.

6. A microscope as claimed in claim 3 or 4, characterized in that the spatial frequency of the sensor elements is at least 1.5 times higher, and preferably at least 2 times higher, than the limit frequency.

7. A microscope as claimed in any one of the preceding claims, characterized in that the filter function (17) is continuous and strictly growing from zero frequency to the position of the peak value and strictly increasing toward zero for increasing frequencies from the position of the peak value.

8. A microscope as claimed in any one of the preceding claims, characterized in that the filter function is a convolution of two one-dimensional filter functions.

9. A microscope as claimed in any one of the preceding claims, characterized in that the filtered image is stored in a storage means (26).

10. A microscope as claimed in any one of the preceding claims, characterized in that it also comprises a display (8) on which the filtered image is shown.

11. A microscope as claimed in any one of the preceding claims, characterized in that the first calculating means is adapted to divide the recorded image into color components, and to provide a digital filter for each of the color components.

12. A microscope as claimed in any one of the preceding claims, characterized in that the first value essentially is one.

13. A method for a microscope, characterized by the steps of arranging an image sensor (5) which has a plurality of sensor elements (6), optics (4, 10) and an object (2) at a mutual distance from each other, so that an image of the object is formed on the image sensor (5), the spatial frequency of the sensor elements (6) being higher than the maximum spatial frequency of the image,

recording the image by means of the image sensor (5),

providing a two-dimensional filter function, which essentially has a first value at the spatial frequency zero, a second value different from zero at a spatial frequency which is higher than the maximum spatial frequency of the image and a peak value between the spatial frequency zero and the spatial frequency of the second value,

(continued)

(continued claim 13)

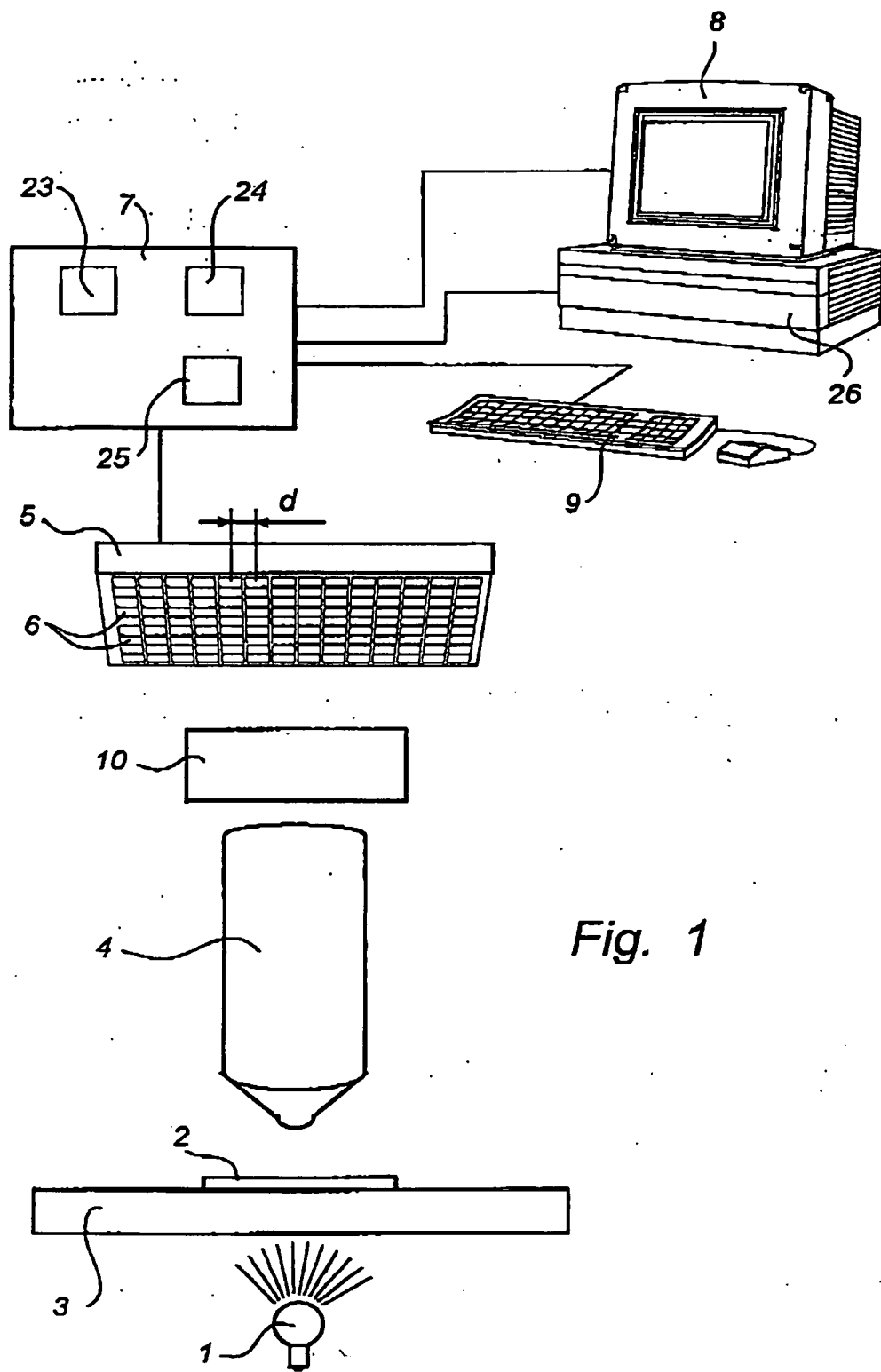
calculating a digital filter which corresponds to a two-dimensional inverse Fourier transform of the filter function, and

filtering the recorded image by means of the digital filter.

### Abstract of the Disclosure

A microscope comprises an object holder (3), optics which in an image plane form an image of an object (2) which is placed in the object holder, a digital image sensor (5) which has a number of sensor elements (6) for recording the image. The image sensor and the image plane are arranged in such manner that the spatial frequency of the sensor elements (6) is higher than the maximum spatial frequency of the image. The microscope further comprises at least a first calculating means (24) which is connected to the image sensor (5) and which is adapted to provide a two-dimensional filter function, which essentially has the value one at the spatial frequency zero, a value higher than zero at a spatial frequency above the maximum spatial frequency of the image and a peak value between said frequencies, to calculate a digital filter corresponding to a two-dimensional inverse Fourier transform of the filter function, and to filter a recorded image by means of the digital filter.

Elected for  
publication: Fig. 1



*Fig. 1*



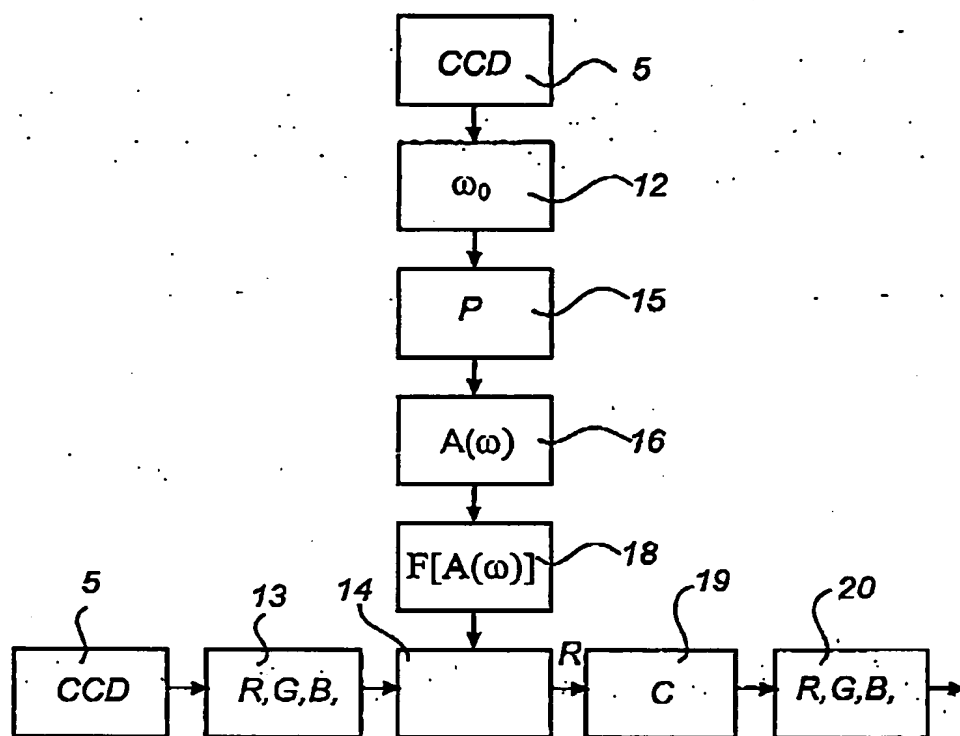


Fig. 2

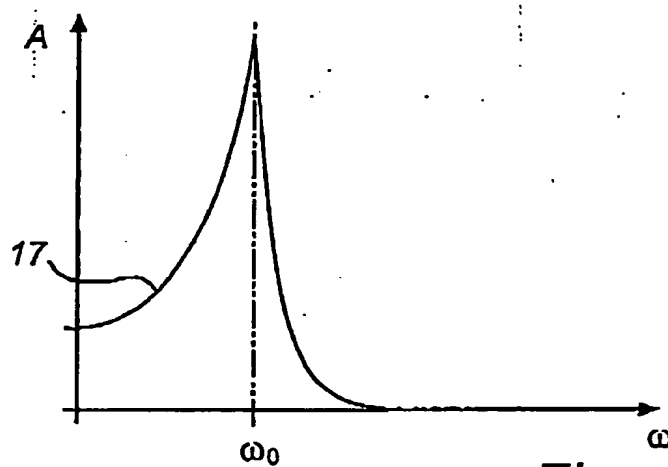
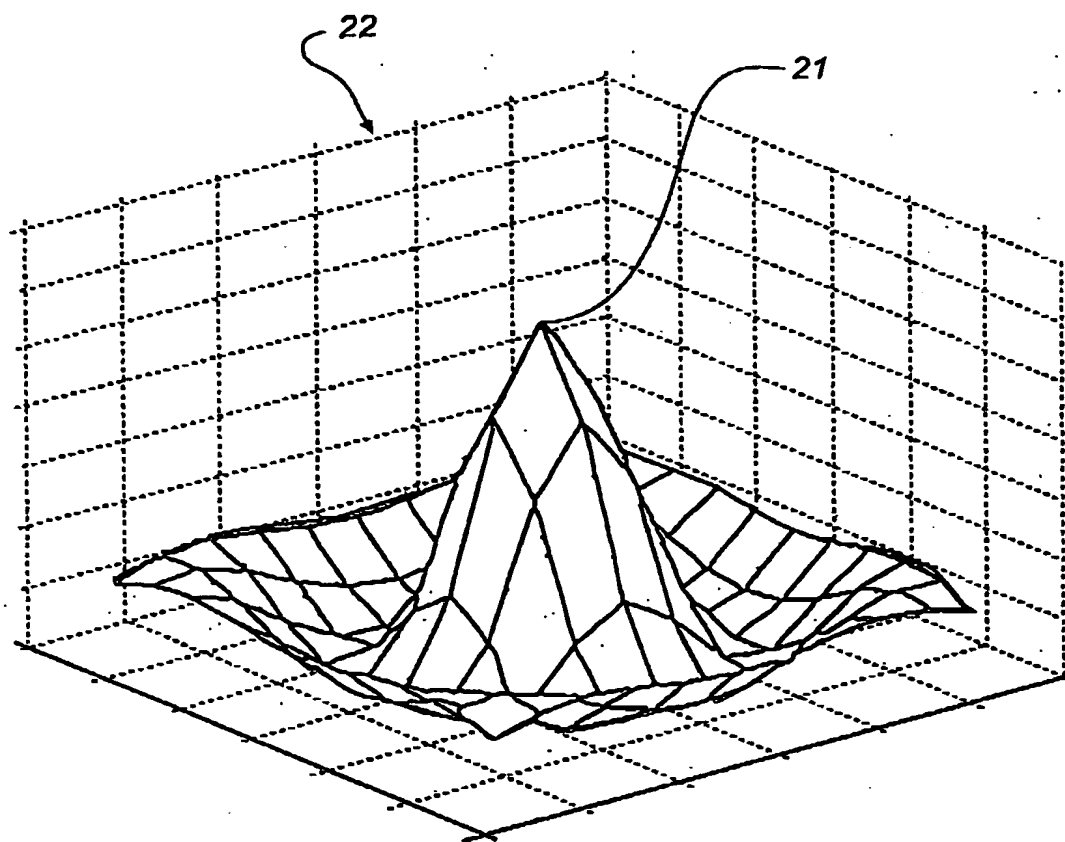


Fig. 3



*Fig. 4*